

EXAMINATION OF SOME ANCIENT INDIAN GLASS SPECIMENS

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In this article Dr. B. B. Lal, Archaeological Chemist in India, critically discusses the chemical constituents of a few ancient Indian glass samples, some of which were analysed and reported on previously and others have been analysed by him for the first time. The present data are admittedly very limited for tracing the chronological and regional developments of ancient glass-making, but when more material of the nature made available in this article is forthcoming, it will be possible to trace the full history of the industry.

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1. INTRODUCTORY

THE origin of glass can be traced to remote antiquity, though when it was first manufactured is an open question.

Actual glass was practically unknown in Predynastic Egypt or in the Old Kingdom, and the occurrence of an impressed Hathor head in a Predynastic grave of Sequence Date 41 has been attributed by Petrie to importation.¹ He is also of the opinion that other specimens of the earliest glass, such as beads from Predynastic burials² were not indigenous to Egypt and those from the First Dynasty and earlier periods were imported from Asia.³ The artificial manufacture of glass can, according to him,⁴ be traced as far back as 2500 B.C. in Syria and 1500 B.C. in Egypt,⁵ where glass of local manufacture is plentiful in the Eighteenth Dynasty, the oldest piece with the date 1551-1527 B.C.—a large ball bead now in the Ashmolean Museum, Oxford,⁶—coming from this period.

There is some evidence to show that Mesopotamia might have been the cradle of glass-industry. Glass beads have been found in large numbers in the excavation of a Third Dynasty cemetery at Ur.⁷ The earliest specimen of glass (blue glass in lumps) as yet recorded in Mesopotamia comes from Abu Shahrein, in a deposit earlier than the Third Dynasty of Ur (2100 B.C.).⁸ Morey has discussed some important problems of

¹ Petrie, *Prehistoric Egypt* (1920), pp. 43, 110.

² McIver and Mace, *El Amroh and Abydos* (1902), p. 54.

³ Petrie in *Trans. Newcomen. Soc.*, 5 (1924-25), p. 72.

⁴ Petrie in *Jour. Soc. Glass Tech.*, 10 (1926), p. 229.

⁵ Lucas, *Ancient Egyptian Materials and Industries* (1934), p. 408; Morey, *The Properties of Glass* (1938), p. 12.

⁶ Lucas, *op. cit.*, p. 116; Morey, *op. cit.*, p. 12.

⁷ Woolley, *Ur Excavations*, II (1934), p. 366.

⁸ Hall, *The Civilization of Greece in Bronze Age* (1928), pp. 71, 104.

ancient glassware,¹ and Thompson has discussed in detail the manufacture of glass as gleaned from Assyrian cuneiform tablets.²

The history of Persian glass is very incompletely known.³ There is no literary document giving information on the production of glass in Iran in remote antiquity.

Until recently it was believed that the earliest specimens of Chinese glass had really been importations from Egypt, and that glass-making became an indigenous industry in China only about the fifth century A.D. It has, however, now been established that glass of indigenous manufacture was in use in China in 550 B.C.⁴ Williamson speaks of Chinese glass made from the rocks in the neighbourhood.⁵ The rocks must have been quartz, an interesting analogy being furnished by Pliny's statement about Indian glass (see below).

The origin of Indian glass is obscure, but there is no doubt that it was known in pre-Christian centuries. According to Mitra, glass was manufactured in Ceylon in the third century B.C.,⁶ and Buch has drawn attention to the fact that the *Arthaśāstra* (probably of Mauryan date, fourth century B.C.) describes false gems as glass gems and mentions the manufacture of glass.⁷ Coomaraswamy is of the opinion that the art of glass-making attained a high degree of perfection even in pre-Mauryan times.⁸ According to Pliny, glass was made in India from fragments of rock-crystal, for which reason Indian glass was 'beyond compare'. He further states: 'the people of India by colouring crystal have found a method of imitating various precious stones, beryls in particular'.⁹ This statement of Pliny has, however, been questioned by Kisa.¹⁰ In Sanskrit literature glass is known as *kācha*, but no details are available about the technique of its manufacture.

Mohenjo-daro and Harappā, the cities of the third millennium B.C., have yielded a large variety of beads, bangles etc., mostly of steatite, paste or faïence. True glass is absent,¹¹ though glazed objects, such as pottery, terracotta beads, steatite and faïence have, no doubt, been found.¹² This is surprising, as the manufacture of glass is not in reality far removed from that of glaze and the Indus valley had cultural contacts with Mesopotamia, where glass-making was an established industry in the third millennium B.C. (above, p.17).

The earliest specimens of authentic glass come from the pre-Mauryan levels of Bhīr Mound, the earliest Taxila, and some of the glass objects unearthed here represent the largest intact examples so far recovered in this country.¹³ Most of them are coloured, and some exhibit a characteristic iridescence due evidently to decomposition and the deposition on the surface of lenticular flakes of silica. The lowest and middle strata of Bhīr Mound have yielded a large number of glass beads of excellent quality.¹⁴

¹ Morey in *Discovery*, XI (1930), p. 61.

² Thompson, *Chemistry of Ancient Assyrians* (1925).

³ Lamm, *Glass from Iran* (1935), p. 7.

⁴ Sartori in *Isis*, 25 (1936), p. 73; White, *Tombs of Old Lo-Yang* (1934), p. 14.

⁵ Williamson, *Journeys in North China*, I, p. 131.

⁶ R. Mitra, *Antiquities of Orissa*, I (1875), p. 101.

⁷ Buch, *Economic Life in Ancient India*, I (1924).

⁸ Coomaraswamy, *History of Indian and Indonesian Art* (1927), p. 16.

⁹ Pliny, *Natural History*, XXXVII, 20.

¹⁰ Kisa, *Das Glas im Altertum* (1908), p. 106.

¹¹ Marshall, *Mohenjo-daro and the Indus Civilization*, II (1931), pp. 469, 574-82.

¹² *Ibid.*, pp. 366, 576-78; Vats, *Excavations at Harappā*, I (1940), p. 312.

¹³ *An. Rep. Arch. Surv. Ind.*, 1919-20 (1922), p. 19; 1921-22 (1924), p. 125; 1922-23 (1925), p. 157.

¹⁴ *Ibid.*, 1919-20 (1922), p. 24.

The art of glass-making had thus reached a high level of technical excellence before the third century B.C. Specimens of ancient glass have been found near Dargai village in the Malākānd Agency (now in Pakistan) along with an earthen pot, which appears to have been employed in manufacturing glass. Other specimens dealt with here come from Bhitā (near Allahabad), Nālandā, Assam, Kurukshetra, Udaigiri in Gwalior,¹ Ahichchhatrā in U.P.² and Arikamedu near Pondicherry.³ Excavation at Brahmagiri⁴ has produced from the Āndhra levels (first-third centuries) a large number of glass beads and bangles of different colours. The chemical composition of these specimens is not known, as the material has not been examined.

Scientific examination of ancient glass has been carried out in the West,⁵ but very little has been done in India in this direction. Though some reports are available,⁶ most of them are incomplete, as physical properties, such as specific gravity, refractive index, strain etc., have not been studied. For want of adequate data on the composition and physical characteristics of firmly-dated specimens definite conclusions as to the source of the material and the technique of fabrication cannot be drawn. It is necessary to emphasize that for the determination of the origin of specimens, small amounts or traces of some ingredients are of paramount importance, and for the study of these minute traces of 'key-elements', spectrography is a very useful technique and has been widely adopted in the West. For example, Ritchie and his collaborators have carried out spectrographic studies on ancient Egyptian glass with very important results.⁷ Ritchie has also examined spectrographically Chinese glass from pre-Han to T'ang times.⁸ Seligman and his co-workers have also carried out extensive investigations on ancient glass with particular reference to its origin.⁹ Spectrographic analysis of glass could not, however, be carried out by the present author for want of laboratory facilities, and he had to content himself with chemical analysis. For the same reason, spectro-photometric methods could not be employed to ascertain what elements were used to produce colour.¹⁰

Subject to the above limitations, it was thought desirable to institute a systematic enquiry into this problem and to correlate the scattered literature on this subject, in order to assess the technical skill attained by the ancient artisans in this line. The published material has been critically examined and reinterpreted in the light of the data now available.

2. GLASS FROM TAXILA

Some specimens of ancient glass from Taxila have already been analysed.¹¹ These analyses are reproduced in Table I (p. 20).

¹ *An. Rep. Arch. Surv. Ind.*, 1922-23 (1925), p. 158; 1930-34, II (1936), p. 300.

² See below, M. G. Dikshit, 'Beads from Ahichchhatrā'.

³ *Ancient India*, no. 2 (1946), p. 96.

⁴ *Ibid.*, no. 4 (1947-48), p. 263.

⁵ Faust, *Antiques*, XXXII (1937), pp. 310-11.

⁶ *An. Rep. Arch. Surv. Ind.*, 1922-23 (1925), p. 158; 1924-25 (1927), p. 139; 1930-34 (1936), p. 300.

⁷ Farnsworth and Ritchie in *Tech. Studies*, VI, no. 3 (1938), pp. 155-68.

⁸ Ritchie in *Tech. Studies*, V, no. 4 (1937), pp. 209-20.

⁹ Seligman and Beck in *Nature*, CXXXIV (1934), p. 982; Seligman, Ritchie and Beck in *ibid.*, CXXXVIII (1936), p. 721; Seligman and Beck in *Bulletin of the Museums of Far Eastern Antiquities*, no. 10 (1935), pp. 1-64.

¹⁰ Norton in *Antiques*, XXXII (1937), pp. 76-77.

¹¹ *An. Rep. Arch. Surv. Ind.*, 1921-22 (1924), p. 125; 1922-23 (1925), p. 158.

TABLE I

Specimens	1	2	3	4	5	6	7	8	9	10	11
SiO ₂	37.09	61.32	39.79	70.57	67.48	68.34	71.01	58.12	53.81	70.69	68.11
Fe ₂ O ₃	...	...	...	1.60	...	1.20	1.84	1.74	8.47	0.81	2.27
Al ₂ O ₃	3.16	1.70	2.45	2.46	3.64	1.67	3.74	5.74	1.51	2.88	2.22
PbO	34.85	Nil	38.93	...	...	...	...	...	...	...	...
SnO ₂	...	...	0.22	...	...	...	...	...	...	...	...
Sb ₂ O ₃	Nil	5.08	...	...	2.42	...	...	...	...	...	...
MnO	0.11	0.26	?	0.05	...	0.34	0.05	0.17	0.08	0.01	...
Cu	...	...	5.31	...	...	...	...	...	...	...	...
CuO	...	...	...	0.55	3.63	...	0.24	...	...	...	0.44
Cu ₂ O	7.20	Nil	...	...	...	...	...	...	...	...	...
CaO	6.46	9.74	2.81	4.60	4.92	8.44	3.73	8.85	6.27	7.05	4.91
MgO	0.70	1.64	?	2.68	1.80	1.44	2.32	4.01	4.50	0.50	3.74
Na ₂ O	10.33	20.26 ¹	10.02	14.99	2.48	17.76	14.99	16.74	23.52	12.86	19.10
K ₂ O	0.87	...	0.57	2.65	0.55	0.94	2.65	4.83	2.35	4.85	...
H ₂ O	...	...	...	...	14.15	0.43	...	...	...	...	...
Total	100.77	100.00	100.10	100.15	101.07	100.56	100.57	100.20	100.51	99.65	100.79

¹ K₂O > 1 per cent.

Description of specimens

1. Red opaque glass.
2. White opaque glass.
3. Thin drawn-out strips of haematinum.
4. Greenish blue glass tiles.
5. Turquoise blue powder of decomposed glass object.
6. Light green glass fragment from flask.
7. Greenish blue glass tile.
8. Amethyst glass fragments.
9. Brown glass fragments.
10. Thin curved fragment of light blue glass.
11. Blue glass bangle.

All these specimens are soda-lime glasses containing appreciable amounts of potash. Most of the specimens are free from air-bubbles.

Specimen 1, described as a red opaque glass similar to Roman haematinum, is very similar in composition to specimen 3, described as thin drawn-out strips of haematinum, as both contain an unusually high proportion of lead, which does not seem to have been found in any other contemporary or earlier glass, except in some blue Chinese beads of the Han period (second century B.C.), analysed by Beck and Seligman.¹ The amount of lead oxide in this specimen was found to be 24.5 per cent, and this is much lower than the lead-content of the two specimens from Taxila described above. The use of lead oxide in large quantities is a recent innovation introduced about the seventeenth century, when crystal glass was made in England. It is, therefore, significant that as early as fourth-third century B.C., craftsmen of Taxila were acquainted with the use of this compound in glass-manufacture. It was, however, not used on a wide scale, as it has been detected only in two examined specimens.

The white opaque glass (specimen 2) and the turquoise blue glass (5) contain a good amount of antimony. The presence of fairly large quantities of antimony is significant, as specimens from other countries have not been found to contain such a high percentage of this element. The addition of antimony in appreciable amounts in special glasses is again a recent development.

Magnesia is present in some specimens but the proportion is not very large, and some magnesia can be substituted for lime with advantage.² Small amounts of magnesia produce glasses which have a rapid melting rate and are easy to work, but high magnesia glass is hard to melt and has a greater viscosity than is produced by an equivalent amount of lime.

The use of small amount of potash such as is present in most specimens from Taxila is an advantage,³ as it increases chemical durability and diminishes its tendency to devitrification.

Most of the specimens also contain a fairly large percentage (6 to 7 per cent) of lime. When too little lime is added, the glass is easy to melt but lacks durability,⁴ while an increase in its proportion produces glass of good chemical durability.⁵

The specimens have a high alkali content (17 to 18 per cent); such glass would have been of a very poor quality had not lime been added in suitable proportions. At the same

¹ Seligman and Beck in *Nature*, *op. cit.*

² Hodkin and Cousen, *Text Book of Glass Technology* (1925), p. 109; Morey, *op. cit.* p. 81.

³ Hodkin and Cousen, *op. cit.*, p. 96.

⁴ Morey, *op. cit.*, p. 80.

⁵ Hodkin and Cousen, *op. cit.*, p. 110.

time, if the proportion of lime is much above 10 to 12 per cent, glass becomes difficult to work¹ and shows a greater tendency towards devitrification. Glass with high silica content (above 72 per cent) has a good chemical durability but becomes very hard and difficult to melt and tends to devitrify. No glass specimen from Taxila shows an unduly high proportion of silica.

Three complete conical flasks of sea-green colour were found at Sirkap, the second city of Taxila.² These, probably the largest specimens of intact ancient glass objects so far found in India, were formed by blowing glass. It has been concluded, therefore, that the Taxila craftsmen were acquainted with the art of glass-making and glass-blowing as well as with the more advanced art of decolourizing glass by means of manganese and colouring it with various metallic oxides. In fact, they confirm Pliny's statement (above, p. 18) that the Indians were skilled in the art of colouring glass to imitate precious gems.

Other important glass objects from Taxila include tiles found in the Dharmarājikā Stūpa erected during the reign of Aśoka (third century B.C.).³ Here, excavation revealed a floor of glass tiles of bright azure blue and a few other colours, viz. black, white and yellow. These tiles average $10\frac{1}{4}$ in. square and $1\frac{1}{8}$ in. in thickness and are of transparent glass, the first complete specimens of their kind so far brought to light. They bear testimony to the specialized knowledge of moulding large objects and possibly also of annealing, for such heavy glass objects require considerable expert attention in annealing for removing internal strain. The state of preservation of the tiles and their freedom from fracture and devitrification demonstrate a high level of technical excellence in manufacture. It is interesting to recall here the Chinese tradition based on the annals of the Wei dynasty (A.D. 386-557) that glass-making was introduced by Indo-Scythian merchants from north-west India.

Varshney has recently commented on Sanaullah's interpretation of these analytical data on Taxila glasses and has made some interesting observations.⁴ He is of the opinion that, contrary to the view of Sanaullah, the origin of Taxila glass was probably quite distinct from that of other antique glass such as Assyrian, Egyptian, Babylonian and Roman. According to him, with the exception of one isolated example of a Babylonian glass from Nippur, dating to about 250 B.C. and having a silica content of 71.14 per cent and a total acidic oxides content of 74 per cent, no single antique glass specimen compares favourably even with the three Taxila glasses (nos. 4, 7 and 10 of Table I) so far as the high silica content of about 71 to 72 per cent and the total acidic oxides content of over 74 per cent of the latter are concerned. These specimens have a high silica content and about 6 to 7.55 per cent of magnesia and lime, while the alkalis are about 17.5 per cent. Even the Nippur sample is distinctly of a different origin, as it has an alkali content of 12 per cent and lime and magnesia content of over 10 per cent. In view of these facts, the suggestion of Sanaullah that Assyrian recipes of glass-making were identical with the Indian ones cannot be maintained. It is, therefore, probable that the origin of Taxila glass was independent of Assyria. However, whether glass was an indigenous invention in India or its knowledge came to India from some other Middle Eastern country is more than can be said in the present state of our knowledge.

3. GLASS FROM NĀLANDĀ

Another site of great archaeological importance that has yielded a large number of glass specimens is Nālandā (District Patna), the most important centre of medieval

¹ Morey, *op. cit.*, p. 80.

² *An. Rep. Arch. Surv. Ind.*, 1919-20 (1922), p. 19; 1922-23 (1925), p. 157.

³ Marshall, *Guide to Taxila* (1936), p. 59.

⁴ Varshney in *Glass Industry*, Dec. 1950.

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Mahāyāna Buddhism. A number of specimens of various colours from this site have been analysed, and the results are reproduced in Table II. Analyses of specimens 1 to 4 have already been published,¹ while the remaining two (5 and 6) have been recently analysed.

TABLE II

Specimens	1	2	3	4	5	6
SiO ₂	62·61	61·21	70·74	61·50	63·44	56·72
Fe ₂ O ₃	1·61	1·60	1·54	9·82	6·90	1·59
Al ₂ O ₃	2·05	1·81	6·13			2·77
FeO	...	...	...	7·01	...	...
MnO	0·06	...	tr.	...	tr.	tr.
CuO	...	...	...	...	1·13	0·79
Cu ₂ O	0·57	0·75	...	0·49	...	...
CaO	6·95	8·15	2·11	5·20	8·00	11·95
MgO	4·17	3·83	0·26	0·06	4·14	3·17
Na ₂ O	17·85	18·25	15·80	15·92 by diff.	15·69	3·62
K ₂ O	5·04	4·98	2·94		1·54	0·49
CO ₂	...	...	...	...	...	12·80
H ₂ O	...	...	...	...	...	7·16
TOTAL	100·91	100·58	99·52	100·00	100·84	101·06

Description of specimens

1. Light blue glass fragment.
2. Sky-blue glass fragments.
3. Green glass rectangular object.
4. Opaque beads of red glass.
5. Blue glass.
6. Decayed glass.

From the table it will be seen that specimens 3 and 4 have got a silica content of 70·74 per cent and 61·50 per cent respectively, and if the R₂O₃ oxides are taken with silica, the acidic oxides go up to 78·41 per cent and 78·33 per cent respectively. The alkalis range from 15·92 per cent to 23·23 per cent, but the lime and magnesia show a wide variation ranging from 2·37 per cent to 15·12 per cent. Specimens 1 and 2 are characterized by comparatively lower values for the acidic oxides, viz. 66·27 per cent and 64·62 per cent respectively. However, their lime and magnesia contents of 11·12 per cent and 11·98

¹An. Rep. Arch. Surv. Ind., 1922-23 (1925), p. 158 ; 1930-34, II (1936), p. 300.

per cent are much higher than those of specimens 3 and 4. The alkalis are also very high, viz. 22.89 per cent and 23.23 per cent. But they are very similar in composition to Taxila specimens 8 and 9 and are softer and less durable than specimens 3 and 4 (Table I). The opaque red beads (4), probably intended as imitation coral, are made of a variety of glass or paste which owes its colour to the presence of ferrous silicate and cuprous oxide. No such material has been discovered elsewhere in India so far. Specimen 6 is decayed glass. The loss on ignition, 12.80 per cent, has been found to correspond to the carbon dioxide given out by the specimen. The carbon dioxide present is equivalent to 21.13 per cent calcium carbonate and 6.63 per cent magnesium carbonate. This analysis shows that the prolonged burial of the specimen in the ground has resulted in the removal of alkalis and carbonation of lime and magnesia. The glass has evidently been attacked by carbonated water. The colouring matter of the glass is copper oxide.

All these specimens are free from lead and antimony. It is, therefore, clear that with the exception of the absence of these two elements, the recipes of glass-manufacture as used at Taxila did not undergo notable modifications down to the time of Nālandā.

4. GLASS FROM MISCELLANEOUS SITES

Some specimens of glass were discovered in 1938 in Dargai village in the Malākānd Agency (N.W.F.P., Pakistan), along with an earthen pot, probably employed for manufacturing glass. The age of these specimens is not known, but they show a striking similarity in chemical composition to Nālandā specimens 1 and 2 (Table II). The results of chemical analysis of two of these specimens are recorded in Table III, in which are also incorporated the analyses of several specimens from a number of other sites in upper India.¹

TABLE III

Specimens	1	2	3	4	5	6	7
SiO ₂	60.48	62.14	85.34	53.25	59.62	76.15	60.15
Fe ₂ O ₃	2.60	1.26	1.72	9.16	3.21	6.33	1.49
Al ₂ O ₃	2.92	2.61	3.88	6.12	3.42	1.97	10.26
MnO	tr.	tr.	...	...	...	...	...
Cu	...	...	...	9.13	...	...	...
CuO	0.68	...	2.53	...	...	...	1.33
CaO	8.67	8.71	2.74	9.18	7.55	4.58	3.27
MgO	2.57	2.97	2.59	1.47	2.03	tr.	2.83
Na ₂ O	19.94	20.09	} 1.20 by diff.	11.69 by diff.	4.10	10.97 by diff.	20.67 by diff.
K ₂ O	2.70	2.68			19.00	...	...
TOTAL	100.6	100.46	100.00	100.00	98.93	100.00	100.00

Description of specimens

1. Blue glass from Dargai in Malākānd Agency.
2. Colourless glass from Dargai in Malākānd Agency.
3. Bluish green bangle, porous and partly decomposed, from Kurukshetra.
4. Small flat coral beads from Assam.
5. Black cylindrical weight of glass from Udaigiri, Gwalior.
6. Glass taurine model from Rairh, Jaipur.
7. Blue glass from flask, Taj Museum, Agra, late Mughul period.

¹An. Rep. Arch. Surv. Ind., 1922-23 (1925), pp. 157-58; 1924-25 (1927), p. 139.

The high proportion of alumina in the specimen from Agra (7) is significant. A certain amount of this ingredient no doubt facilitates the working of glass¹ and is a frequent constituent of glass, as it gives greater chemical durability, lower coefficient of expansion and greater freedom from devitrification, thus rendering it resistant to sudden changes in temperature. But the amount contained in the flask is excessive, as alumina above 4 per cent increases the viscosity of glass, making it difficult to melt and work. The specimen from Jaipur (6) is highly silicious containing relatively small amounts of lime, magnesia and alkalis.

5. GLASS FROM AHICHCHHATRĀ AND ARIKAMEDU

Some specimens of glass were found at Ahichchhatrā in the course of excavation conducted there during 1940-44. This ancient site represents the capital of North Pañchāla (northern Gangā-Yamunā Doab) and was in occupation from the third century B.C. to the tenth-eleventh century A.D.² Two specimens (1-2) belonging to Stratum VI (first century) have been analysed and the results are recorded in Table IV. They show that the colour of the blue specimen (1) is due to copper oxide, and that of the green one (2) to the combined effect of copper and lead oxides. It is very probable that these substances are frits employed for glazing pottery.

Table IV also shows the results of chemical analysis of two specimens recovered from excavation at Arikamedu³ near Pondicherry.

TABLE IV

Specimens	1	2	3	4
SiO ₂	61.49	59.56	73.62	72.49
Fe ₂ O ₃	5.29	5.40	3.84	6.50
Al ₂ O ₃	0.66	0.05	1.38	1.12
PbO	...	4.23	0.07	0.07
MnO	...	0.06	5.01	1.99
CuO	2.39	1.82	...	...
CaO	6.60	6.54	1.96	2.94
MgO	4.61	4.34	0.30	0.68
P ₂ O ₅	1.94	1.36	...	...
Na ₂ O	15.32	14.19	1.30	0.20
K ₂ O	2.67	2.41	12.78	14.14
TOTAL	100.97	99.96	100.26	100.13

¹ Morey, *op. cit.*, p. 81.

² Ghosh in *Ancient India*, no. 1 (1946), pp. 37-40.

³ Wheeler in *ibid.*, no. 2 (1946), pp. 96-97.

Description of specimens

1. Blue glass from Ahichchhatrā.
2. Green glass from Ahichchhatrā.
3. Deep violet glass from Arikamedu.
4. Bluish violet glass from Arikamedu.

Specimens 3 and 4 were recovered from unstratified deposits at Arikamedu, a coastal centre of trade with the Roman world during the first-second centuries A.D. It is, therefore, of interest to examine whether they came from Rome or were of indigenous manufacture. The specimens were deeply coloured, unshaped, uncut lumps of clear glass and appeared to have undergone some decomposition on account of their prolonged burial in the soil. Examination has shown that both these specimens are potash glasses containing very little alumina and lime. The silica content is very high (73·62 to 72·49 per cent) and if the R_2O_3 oxides are taken together with silica, the acidic oxides go up to 80·11 to 78·84 per cent. The alkalis, mostly potash, account for 14·08 per cent to 14·34 per cent. Both these specimens, therefore, represent hard and durable glasses, showing little tendency towards devitrification. Large amounts of lime and alumina tend to cause devitrification of glass, but the amount of these components is low, a fact which explains their freedom from devitrification. The violet glass (3) is more or less transparent and contains a high proportion of manganese, which accounts for its deep violet colour. The bluish violet specimen is also a potash glass containing manganese as the colouring agent. This specimen was, however, very heterogeneous, and small bits of green glass could be easily picked out of the specimen. These glasses appear to be of indigenous manufacture, as no features connect them with the West.

A comparison of the chemical composition of these specimens with that of north Indian specimens shows that, with the exception of the specimen from Udaigiri (5, Table III), which is a potash glass, the latter are soda-lime glasses, whereas the Arikamedu specimens are potash glasses. In this connexion it has to be considered that being near the sea it may have been convenient to use the wood ash (potash) for glass-making rather than to collect soda from the drier interior for the purpose.

6. CONCLUSION

From the analytical data on ancient Indian glasses recorded above it will be seen that barium has not been used at all, and the use of lead is attested by only two samples from Taxila and one from Ahichchhatrā. That lead was used in large quantities (24·5 per cent) in Chinese glass of the Han period (second century B.C.) has been shown by Beck and Seligman (above, p. 21). These workers have also reported the presence of 19·2 per cent of barium oxide in this specimen. Indian glass is, therefore, quite distinctive in this respect.

When the art of glass-blowing began to be practised in India is difficult to say, as most of the ancient specimens are fragmentary and some represent glass in the crude stage in the form of unshaped lumps. The beginning of the art of glass-blowing has been dated by Kisa to a little before the beginning of the Christian era,¹ and this view seems to be supported by the three sea-green flasks from Sirkap (above, p. 22). The excellent state of preservation of the flasks from Taxila further shows that they had been annealed

¹ Kisa, *op. cit.*, pp. 296-99.

after blowing. Glass tiles recovered from the Dharmarājikā Stūpa at Taxila (above, p. 22) also show that the art of moulding large glass objects had attained a high degree of perfection, and clear transparent glass could be manufactured on a large scale. As these large heavy tiles were free from devitrification and fracture, they also had probably been carefully annealed after moulding.

That the fabrication of glass vessels continued to be practised during later periods is proved by the discovery of an entire glass object of excellent workmanship during the excavations at Brāhmanābād (Sind),¹ where Cousens recovered 'a dainty little bowl of blue glass that seems to have been overlaid with white or cream enamel. But most of this has peeled off, the flaking and disintegrating surface showing these iridescent colours peculiar to mother-of-pearl.' From this description it appears that the iridescent effect was caused by the decomposition of glass and the so-called enamel may have been the product of chemical alteration. In view of the rarity of entire glass objects a sample of this glass was not available for chemical analysis.

It has recently been reported by Nagar² that Kōpiā, a village about 30 miles from Basti (U.P.), marks an ancient centre of glass-manufacture. He has reported the discovery of a large number of tiny glass beads with very fine threading holes, a large variety of glass pendants, beads, bangles and lumps of glass. According to him, the beads are typologically similar to the beads etc. found by Peppé in the Buddhist stūpa at Piprahwa,³ 35 miles from Kōpiā, and he has concluded that these glass specimens go back to the fifth century B.C. The author has recently inspected the site and collected, in addition to the types in Nagar's collection, a number of glazed sherds of different colours. An age-value should not be attached to these relics, of which the stratigraphical position is unknown, and a well-directed excavation of the site is necessary for a precise dating of these finds. The beads and glazed pottery collected by the author are under investigation, and the results are likely to contribute materially to our knowledge of the composition and properties of ancient glass and the technique of its manufacture. The discovery of glass of different colours and of glazed pottery of Kōpiā type has recently been made by Banerji at Sayadpur Bhitari,⁴ about 48 miles from Banaras, and the author is engaged in a study of these specimens with a view to correlating, if possible, the glass-industries of these two sites and establishing their chronology on internal evidence.

¹ *An. Rep. Arch. Surv. Ind.*, 1908-09 (1912), p. 82.

² Nagar in *Amrita Bazar Patrika*, 14th Aug., 1949.

³ Peppé in *Jour. Royal Asiatic Soc.*, 1898, p. 573.

⁴ Information from Mr. A. C. Banerji, Curator, Archaeological Museum at Sarnāth. Bhitari is a well-known ancient site with a pillar-inscription of the reign of Skanda-gupta of the fifth century A.D. : Fleet, *Corpus Inscriptionum Indicarum*, III (Calcutta, 1888), p. 52 ; also Führer, *The Monumental Antiquities and Inscriptions in the North-Western Provinces and Oudh* (1891), p. 228.